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Examination of Balance Measures Produced by the Biodex Stability System

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Objective: Our purpose was to establish normal patterns and relationships of stability using the Biodex Stability System.

Design and Setting: The design of this study used both nonexperimental and quasi-experimental methods. All testing was performed in a university sports medicine laboratory.

Subjects: Nineteen healthy subjects (8 males, 11 females, age = 24.4 ± 4.2 years; wt = 70.5 ± 20 kg; ht = 171.2 ± 11.7 cm) with no history of lower extremity injury participated in this study.

Measurements: For data analysis, the medial/lateral stability index (MLSI), anterior/posterior stability index (APSI), overall stability index (OSI), and time-in-balance scores were recorded.

Results: Multiple regression revealed that APSI and MLSI significantly contributed to the OSI, with the APSI accounting for 95% of the OSI variance. Additionally, the percentage of time spent between 0° and 5° from level was significantly greater than the time spent between 6° and 10°, 11° and 15°, and 16° and 20°. Furthermore, the percentage of time spent between 6° and 10° was significantly greater than the time spent between 16° and 20°.

Conclusions: These data suggest that uninjured individuals spent the majority of the time balanced within 0° to 5° from level and progressively less time at greater angles. Additionally, the data suggest that the OSI is very closely related to the APSI and receives a relatively small contribution from the MLSI. Because of this small contribution, if the clinician is interested in both anterior-posterior and medial-lateral motions, it may be best to use the MLSI and APSI separately rather than the OSI.

Key Words: postural control, proprioception, regression analysis

In the past, several systems[1–6] have been used to assess balance and postural control. These devices have typically used force plates combined with computer software to determine the movement of the center of pressure (COP). Center of pressure is the central point of pressure that is applied to the foot during contact with the ground or the point of application of the ground reaction force on the foot.[7] During stance, the COP can be used to measure the movement of the individual's center of gravity over the foot. Thus, the COP can be used to index the amount of movement or sway of the center of gravity during stance. Using this method, Tropp et al[6,8] have examined single-leg stance stability patterns in individuals with functionally unstable ankles.

In contrast to force plate systems, the Biodex Stability System (BSS) (Biodex, Inc, Shirley, NY) uses a circular platform that is free to move about the anterior-posterior (AP) and medial-lateral (ML) axes simultaneously. In addition to moving about these axes, it is possible to vary the stability of the platform by varying the resistance force applied to the platform. Springs apply this force to the underside of the platform and can be adjusted to preset resistances established by the manufacturer. Rather than measuring the deviation of the COP during static conditions, this device measures the degree of tilt about each axis during dynamic conditions. Thus, the BSS appears to provide more specific information on ankle joint movements. However, it is unclear how knee and hip motions affect BSS measures or how these measures relate to COP fluctuations.

From the degrees of tilt about the AP and ML axes, the BSS calculates the medial-lateral stability index (MLSI), the anterior-posterior stability index (APSI), and the overall stability index(OSI) (Figure 1). These indexes are standard deviations assessing fluctuations around the zero point (ie, horizontal) rather than around the group mean. The MLSI and the APSI assess the fluctuations from horizontal along the AP and ML axes of the BSS, respectively. In contrast, the OSI is a composite of the MLSI and APSI and, thus, is sensitive to changes in both directions.

In addition to these measures, the system calculates percentage of time in balance for 5° concentric rings (zones) as well

$$APSI = \sqrt{\frac{\sum(0-Y)^2}{\#\ \text{samples}}}$$

$$MLSI = \sqrt{\frac{\sum(0-X)^2}{\#\,samples}}$$

$$OSI = \sqrt{\frac{\sum(0-Y)^2 + \sum(0-X)^2}{\#\,samples}}$$

Figure 1. Formulas for calculating the anterior-posterior stability index (APSI), medial-lateral stability index (MLSI), and overall stability index (OSI).

as for the quadrants around the foot tested (Figure 2). For example, if a 30-second test is performed on the BSS and the individual tested remains balanced in the smallest ring (0° to 5°) for 15 seconds, the system reports a score of 50% for the first ring. If 10 seconds are spent in the second ring (6° to 10°), a score of 33% is reported for the second ring, etc. The BSS also applies this procedure to the 4 quadrants. Thus, the system allows the clinician to establish patterns of time spent away from horizontal as well as standard deviations away from horizontal.

While there has been some research evaluating the reliability of the BSS,[9] we were unable to find any studies examining stability patterns within the zones or quadrants. However, Tropp et al[4,6,8] demonstrated that individuals with functionally unstable ankles have a greater dispersion in their COP during single-leg stance. Thus, it seems reasonable to speculate that the amount of time spent in these zones or quadrants may reveal proprioceptive disabilities associated with ankle or lower extremity pathology. Furthermore, there appear to be no existing data examining the relationship between the OSI and the MLSI and APSI. Thus, the goal of our study was to determine normal stability patterns using the BSS and to assess the relationship of MLSI and APSI to OSI.

METHODS

Subjects

Nineteen healthy subjects (8 males, 11 females, age = 24.4 ± 4.2 years; wt = 70.5 ± 20 kg; ht = 171.2 ± 11.7 cm) with no prior lower extremity injury volunteered and gave informed consent to participate in the study. All procedures were approved by the University of Virginia's institutional review board.

Testing Procedures

Subject preparation. Our study design was a pre-experimental 1-time observation with no treatments. All subjects reported to the laboratory on 2 days separated by 24 hours. The first day was a familiarization session, which consisted of 5 practice sessions using the testing protocol. Subjects stood on the BSS with the leg they would use to kick a ball. They were allowed to flex the support knee to no more than 10° but were required to maintain an upright posture with the supporting leg. Additionally, subjects were instructed to keep their hands at their sides and to maintain a comfortable knee angle with the unsupported leg during testing. Once in this position, the stability platform was unlocked to allow motion. The subjects were then instructed to adjust the supporting foot's position until they found a position at which they could maintain platform stability. This was done to establish the subjects' ideal foot positioning for testing. The platform was then locked, and subjects were told to maintain the foot position. This position was used for testing.

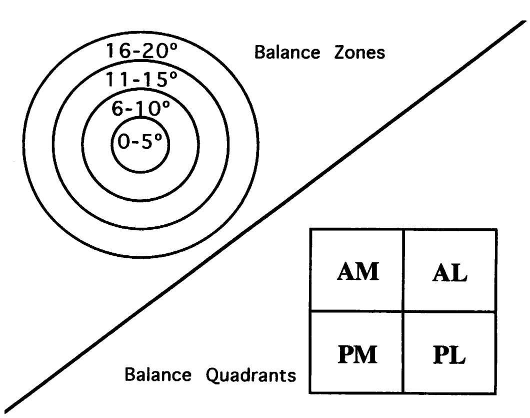

Figure 2. *Zones and quadrants used to calculate percentage of time.*

Testing protocol. The testing protocol consisted of a single[10,11] 30-second[11] test using all 8 resistances provided by the BSS. We used a single test to reduce the potential effects of learning and fatigue. The intratester reliability of this procedure has been previously reported as 0.43 for MLSI, 0.80 for APSI, and 0.82 for OSI.[12] The force of each resistance level was predetermined by the manufacturer's design, using 8 springs located at the perimeter of the balance platform. Each spring was manufactured from music wire. The springs had an uncompressed length of 13.97 cm, an outside diameter of 3.11 cm, a wire diameter of 0.24 cm, and a spring rate of 13.81 N/cm. When compressed to 7.52 cm, the spring produced 88.9 N of force. The resistance order declined from the most resistant to the least resistant, with each resistance lasting 3.75 seconds. BSS software sampled the degree of tilt from level in the medial-lateral (X) and anterior-posterior (Y) directions at a rate of 20 Hz. These signals were then converted to MLSI, APSI, and OSI values (Figure 1). Additionally, the BSS software used the X and Y signals to calculate the percentage of time in quadrants and zones (Figure 2). If trial subjects lost their balance during the testing, they were permitted to briefly toe touch with the opposite foot or grasp the handrails temporarily to re-establish balance. If subjects were unable to quickly regain their balance, the trial was deleted. Otherwise data collection continued during balance correction.

Statistical Analysis

With the data from the test trial, we performed a stepwise multiple regression using the MLSI and APSI to predict the OSI. The purpose of this analysis was to decompose the OSI into its 2 component parts to determine whether the OSI was biased toward one of its components. Additionally, a 1-way repeated-measures analysis of variance (ANOVA) was performed to test differences in percentage of time in each quadrant (4 levels), and a second 1-way repeated-measures ANOVA was performed to test differences in percentage of time in each zone (4 levels). ANOVA post hoc testing was performed using the Tukey honest significant difference test. The significance level of all statistical tests was set at $\alpha < .05$.

RESULTS

The means and standard deviations for OSI, MLSI, and APSI were $4.07° \pm 1.63°$, $1.77° \pm 0.91°$, and $3.71° \pm 1.58°$, respectively. In the first step of the regression analysis, the APSI entered the regression equation with $R = 0.972$ and $R^2 = 0.944$ ($P < .00005$). On the second step of the regression analysis, the MLSI entered the regression equation, producing $R = 0.998$, $R^2 = 0.996$, and R^2 change $= 0.053$ ($P < .00005$). The results of the first ANOVA revealed no significant differences ($F_{3,18} = 0.8$, $P = .497$) in the time spent in the 4 quadrants (Figure 3). In contrast, the second ANOVA revealed significant differences ($F_{3,18} = 323.32$, $P < .0005$) in the time spent in the 4 concentric zones. Post hoc testing revealed that the percentage of time spent between 0° and 5° was significantly greater than that of the other 3 zones and that the time spent between 6° and 10° was greater than the time spent between 16° and 20° (Figure 4). Finally, the ANOVA for the stability indexes produced a significant difference among the indexes ($F_{2,18} = 42.64$, $P < .0005$), with post hoc testing revealing that MLSI was smaller than either APSI or OSI (Figure 5).

DISCUSSION

The multiple regression indicates that 95% of the variance in the OSI can be accounted for by the APSI, suggesting that OSI and APSI are nearly identical. This is clearly indicated by our plot (Figure 6) of individual subject scores for OSI, APSI, and MLSI. A departure between OSI and APSI began with subject 11. We believe this is due to the relatively low APSI. Based on the OSI formula, MLSI and APSI have equal weights. Thus, as APSI declines, MLSI has more effect on OSI. Conversely, when subjects have a relatively large APSI, ie, approximately −1 standard deviation or greater (subjects 13–19), the MLSI must approach 1 standard deviation above its mean before it is large enough to have much of an effect on OSI. It is worth noting that the largest departure of APSI and OSI occurred with subject 13, who displayed a high MLSI combined with a relatively low APSI.

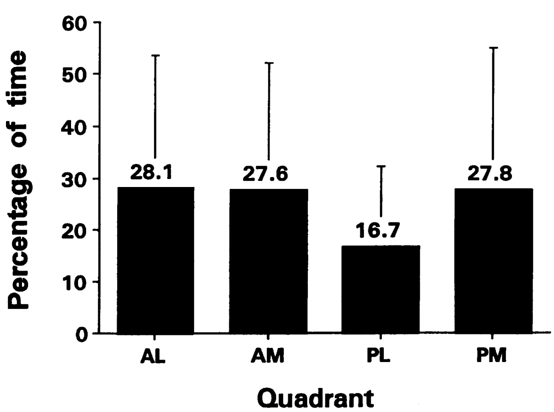

Figure 3. Means and standard deviations for percentage of time in anterolateral (AL), anteromedial (AM), posterolateral (PL), and posteromedial (PM) quadrants.

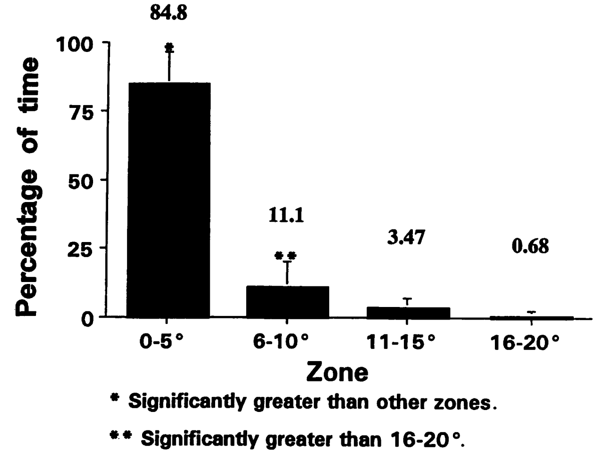

Figure 4. Means and standard deviations for percentage of time in zones.

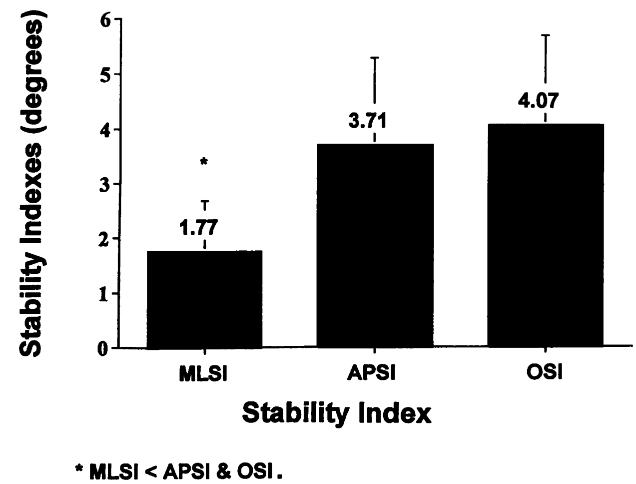

Figure 5. Means and standard deviations for medial-lateral (MLSI), anterior-posterior (APSI), and overall stability (OSI) indexes.

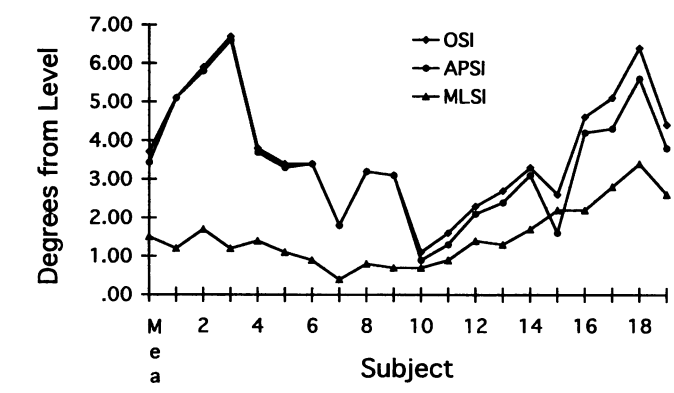

Figure 6. Individual subject scores for anterior-posterior stability index (APSI), medial-lateral stability index (MLSI), and overall stability index (OSI).

Another explanation for MLSI's smaller contribution may be its low reliability. Previous research has shown that the intratester reliability of MLSI is only 0.43.[12] This suggests that a great deal of error is associated with this measure. It is reasonable to suspect that this higher error rate diminished MLSI's effect on OSI.

In addition to the regression analysis, we performed an ANOVA on the 3 stability indexes. The MLSI was smaller than either the APSI or the OSI. Our finding that APSI was larger than MLSI is contrary to other studies using single-leg stance and COP measures.[10,13–16] In each of these studies, AP sway and ML sway were reported as being approximately equal.

The explanation for the differences between our results and others appears to be related biomechanical factors, BSS design, and, possibly, anatomical factors. A biomechanical explanation of the differences in AP and ML motion may be the location of the body's COP during single-leg stance. Using the data of Murray et al,[17] we estimated that the COP was located anterior to the AP motion axis and lateral to the ML motion axis, with the anterior distance being greater than the lateral. This suggests that there is a greater gravitational torque around the AP motion axis than around the ML motion axis, producing greater AP motion. Additionally, force fluctuations parallel to the AP motion axis have been shown to be greater than force fluctuations parallel to the ML motion axis.[13] These increased forces may be the result of greater muscular activity of the muscles controlling rotation (ie, invertors and evertors) about the ML motion axis. Thus, we believe that the increased rotation around the AP motion axis may be due to a greater gravitational moment around that axis and increased muscular stability around the ML motion axis.

The reason for greater single-leg stance AP motion than ML motion may also be related to anatomical factors. Anatomically, there is a greater range of motion available in the ankle's AP plane than in its ML plane. Since the BSS measures rotation about the AP and ML motion axes rather than postural sway, these differences may also represent differences in the available range of motion.

Based on these findings, we believe that MLSI and APSI may be best used separately rather than combined in the OSI. Because the MLSI contributes a very small portion to the OSI, clinically important ML instabilities might be overlooked if only the OSI were used. If an OSI is desirable, one solution might be to normalize anterior-posterior and medial-lateral motions to the physiologically available motions in these planes. Thus, the OSI would represent relative amounts of motion within the available physiologic ranges.

With regard to the time spent in quadrants and zones, our findings were not surprising. We had expected that uninjured individuals would stay near the level platform position. This is consistent with previous force plate studies[4,6] that measured the COP's area of dispersion. These studies found that individuals with functional ankle instabilities had greater areas of dispersion than did uninjured individuals. It should be emphasized that the measurement techniques of these previous studies and ours are very different, which makes direct comparison difficult. Thus, we suggest that future BSS research use injured populations and examine the relationship of BSS measures to other measures such as COP.

In addition to the above studies using single-leg stance,[4,6,8,13,14] several others[18–21] have used the Chattecx Balance System (Chattanooga Group Inc, Chattanooga, TN) to study single-leg stance. Unfortunately, these studies used the Chattecx system's postural sway index. Similar to the BSS OSI, the postural sway index is a composite of ML and AP sway, and, thus, cannot be compared with ML and AP sway measures.

Finally, the intent of our study was to establish normal patterns of balance on the BSS. However, our measures did not account for brief losses of balance. For example, in our study, subjects were allowed to briefly toe touch to regain their balance. Thus, it is possible that 2 individuals could have had the same BSS scores despite one subject's having toe touched while the other did not. Clearly, these individuals would not have the same balance ability. We believe future researchers should establish the relationship between BSS scores and toe touches.

In conclusion, we found that MLSI accounted for a very small portion of the OSI variance. Thus, clinicians may find it more useful to use APSI and MLSI separately to assess balance. Furthermore, we found that uninjured individuals had a tendency to spend most of the balance time within 0° to 5° from horizontal, with no differences in time spent within the 4 quadrants.

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